Final Report

Contract Number	N00014-05-1-0135
Title of Research	AlGaN/GaN HEMTs on semi-insulating GaN substrates by MOCVD and MBE
Principal Investigator	Dr Umesh Mishra
Organization	University of California, Santa Barbara

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Abstract

Silicon (Si) implantation into AlGaN/GaN high electron mobility transistors (HEMTs) has been studied in this program as a method to reduce the sharp increase in the dynamic source resistance at increasing current levels that result in a reduction both in the transconductance g_m and the current gain cut-off frequency f_T.

During the program two different approaches have been investigated to decrease the electric field in the source access region. To prevent breakdown between source and gate, different barrier layers have been investigated. Ultimately, these barriers allow an overlap between the gate and the source implant region.

First, a regrown AlGaN/GaN channel as the barrier between the source implant region and the gate has been investigated. In the past, silicon has been found to create a buried parasitic layer conductive path at the re-grown interface. In this work, multiple-cycle treatment with hydrofluoric acid and ozone was used to reduce the silicon at the regrowth interface by 80%.

Second, using silicon nitride (SiN) as the barrier layer between the implanted source region and the gate allowed a regrowth free structure. MOCVD grown SiN was deposited in situ after the activation anneal of the implanted silicon.

With channels lengths down to 0.3 μm and gate lengths of 200 nm, these devices exhibited constant dynamic source resistances which improved the transconductance linearity at high current levels significantly.

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Introduction

AlGaN/GaN HEMTs have demonstrated record power densities at microwave operation [1]. However, these devices usually exhibit a fast decrease in current gain cut-off frequency f_T. Most of the decrease in f_T can be attributed to the decrease of g_m at high currents. This decrease can be explained by the increase of the small signal source access resistance, r_s, with drain current. Since the electron velocity varies with the electric field, a decrease in the electron mobility for high fields is most likely the reason for this increase of access resistance [2].

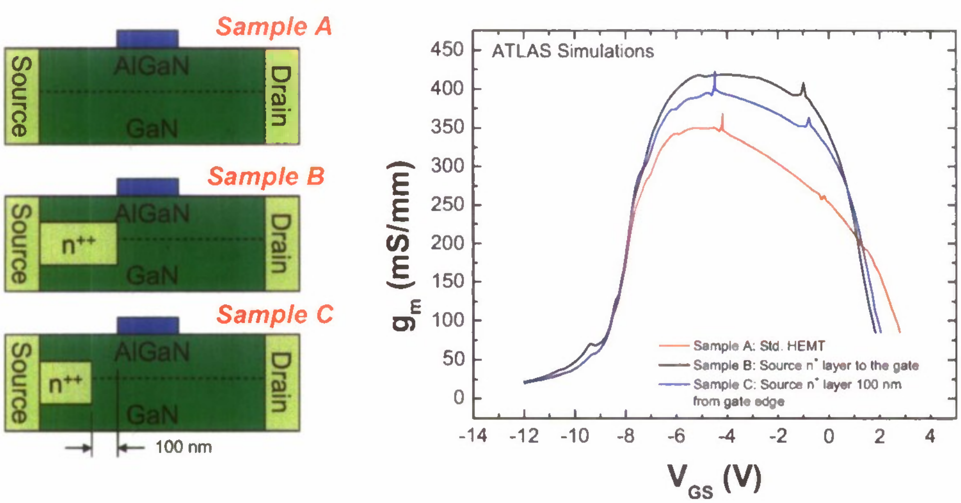

Fig 1: Left: Proposed structures to increase the linearity of g_m and f_T. Right: Simulated g_m profiles by ATLAS

A g_m linearity improvement can be achieved if the electric field at the source can be kept below its quasi saturation value (~10 kV/cm). ATLAS simulations have shown that an introduction of low resistivity areas between the source and the gate can improve the linearity (Fig 1), [2].

To create the structure Sample B in Fig. 1, ion implantation is a promising technology after excellent low sheet resistances as low as 14 Ohm/ Square have been demonstrated [3]. An important feature of this structure is the barrier layer that separates the gate from the implanted source region, avoiding high leakage current or even breakdown between the gate and source.

In this program, two different approached have been investigated to form this barrier layer. The results are described in the following section.

Barrier layer by channel regrowth

Figure 2 shows a schematic cross section of the AlGaN/GaN HEMT with buried implants. The barrier between the implanted source region and the gate consists of a regrown AlGaN/GaN channel.

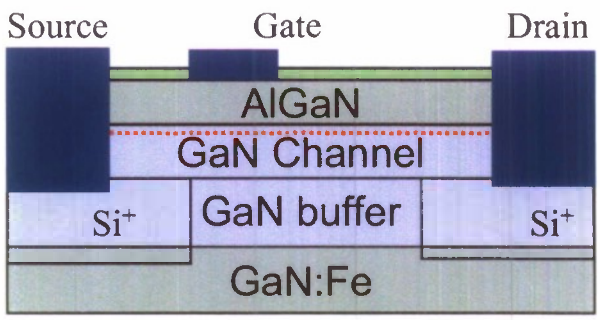

Fig 2: AlGaN/GaN HEMT with buried Si- implants

The process flow involves implanting highly doped source and drain regions into an insulating GaN substrate and then regrowing the GaN channel and AlGaN barrier layer. A significant challenge in this approach is the formation of a Si layer on the surface after removing the GaN substrate from the growth chamber (MBE and MOCVD) and preparing it for implantation. In a regrown HEMT structure, this Si layer forms a parasitic conductive leakage path parallel to the 2 DEG.

To mitigate this effect, a cycled UV ozone treatment was employed. Prior to regrowth, the GaN buffer surface was exposed twice to a 5 min ozone treatment followed by 30 sec hydrofluoric acid (HF) dip. Ozone treatment enhances the oxidation of the Si layer. HF treatment then removes the formed oxide layer.

Figure 3 shows the DC IV curve of a regrown AlGaN/GaN structure with (a) no ozone treatment and (b) cycled ozone treatment before regrowth.

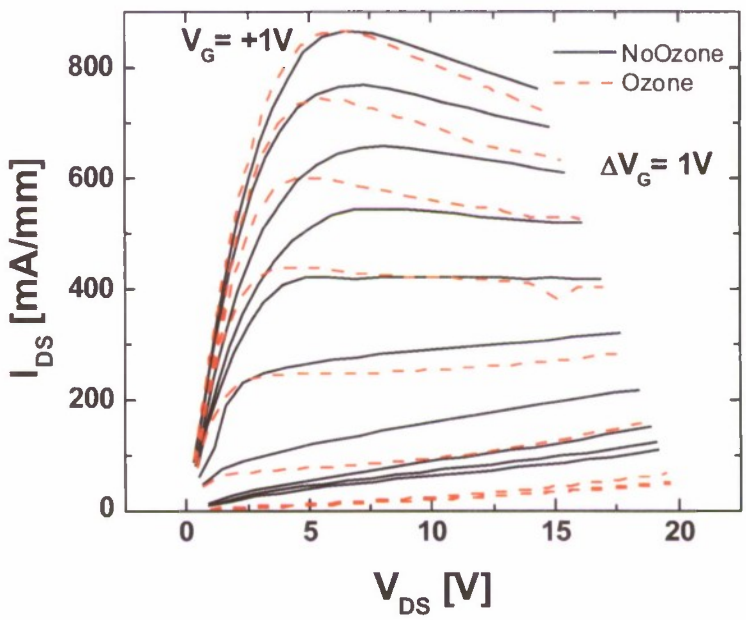

Figure 3: DC I-V curve of regrown AlGaN/GaN HEMT (a) with ozone/HF treatment and (b) no treatment before regrowth.

It can be observed that both devices do not pinch off. Nevertheless, a reduction in leakage current for the ozone treated sample is obvious. An 80% reduction of silicon concentration at the interface was observed. Although significant, this reduction was not sufficient for transistor applications. Further cycling of ozone and HF treatment did not completely remove the parasitic layer.

Buried Implant by metal insulator semiconductor heterostructure FET (MISHFET)

The second approach under this program was the investigation of an AlGaN/GaN metal insulator semiconductor heterostructure FET (MISHFET) structure that allows the overlap of gate and implanted source region (Fig. 4).

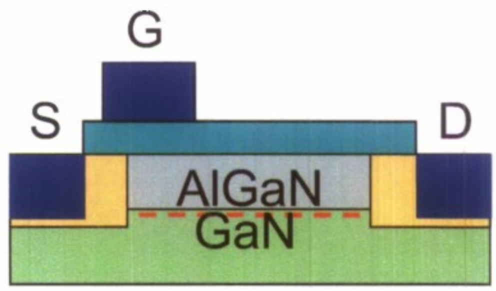

Figure 4: Schematic of an AlGaN/GaN metal insulator semiconductor heterostructure FET (MISHFET)

Previously, ion implantation has been demonstrated to be an excellent choice to form contact resistances as low as 0.2 Ωmm to HEMT structures [4]. Figure 4 shows a schematic of the MISHFET structure.

Fabrication of the MISHFET started with deposition of a SiO_2/Ti/Ni ion implantation mask with Ti/Ni removed in the source and drain regions (S/D) for implantation. Source to drain spacing was 0.4 μm. Si ions at a dose of 1×10^{16} cm^{-2} were implanted at 0° at 60 keV at room temperature. After the implantation mask was removed the sample was subject to an activation anneal for 30 sec at ~1280 °C in an MOCVD system flowing N_2 and NH_3 at atmospheric pressure (760 Torr). A 5 nm SiN layer was deposited in situ. The AlGaN layer was removed in the S/D regions using Cl_2 reactive ion etching (RIE) and ohmic

Ti/Au/Ni contacts were deposited onto the underlying implanted GaN. A contact resistance of 0.5 Ωmm was obtained. Ni/Au/Ni gates were formed by ebeam lithography (300 nm). The overlap between the implanted source region and the gate was 100 nm.

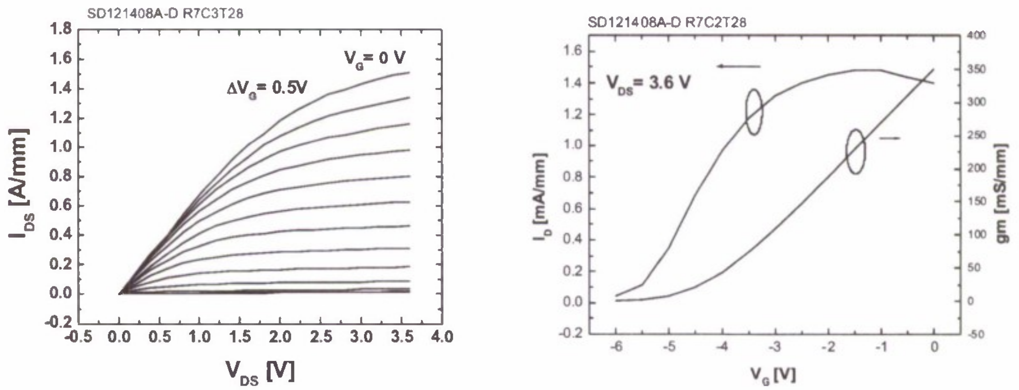

Figure 5: Left: DC-IV curve; Right: g_m-I_D curve of 0.4 μm channel MISHFET

Figure 5 left depicts the DC IV curve with a maximum drain current of 1.5 A/mm at a drain bias of V_{DS}=3.6 V. Figure 5 right shows g_m and I_D versus gate voltage. The device exhibits a maximum transconductance of 350 mS/mm and the drop of g_m at high current is minimal.

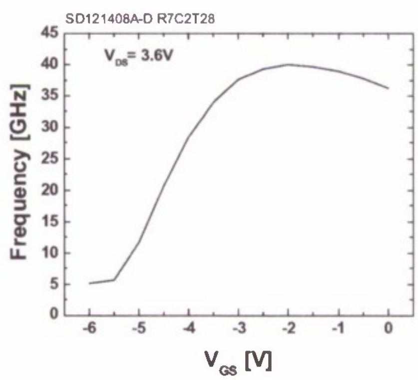

Figure 6: Current-gain cutoff frequency f_T versus gate voltage

Figure 6 shows f_T versus gate voltage. The sharp drop in g_m and f_T as described by Palacios et al. [2] is not observed.

References:

[1] Y.F. Wu , A. Saxler, M. Moore, R.P. Smith, S. Sheppard, P.M. Chavarkar, T. Wisleder, U.K. Mishra, and P.Parikh, "30 W/mm GaN HEMTs by field plate optimization," IEEE Electron Dev Lett, vol. 25, no. 2, pp. 117-119, Feb 2004

[2] T. Palacios, S. Rajan, A. Chakraborty, S. Heikman, S. Keller, S.P. DenBaars, U.K. Mishra, "Influence of the Dynamic Access Resistance in the g_m and f_T Linearity of AlGaN/GaN HEMTs, " IEEE Trans. Elect. Dev, vol 52, no 10, pp 2117-2123, Oct 2005

[3] H. Yu, L. McCarthy, S. Rajan, S. Keller, S. DenBaars, J. Speck, U. Mishra," Ion Implanted AlGaN/GaN HEMTs With Nonalloyed Ohmic Contacts," IEEE Elect Dev Lett, vol 26, no 5, pp 283-285, May 2005

[4] F.Recht, L. McCarthy, L. Shen, C. Poblenz, A.Corrion, J.S. Speck, U.K. Mishra, "AlGaN/GaN HEMTs with large angle Implanted Nonalloyed Ohmic Contacts," 65th Device Research Conference, South Bend, IN, 2007

Dear Sir or Madam,

Please find attached the final report for N00014-05-1-0135 (UC Santa Barbara, Prof. Mishra).

I apologize for the delay.

Best Regards,

Felix Recht

ECE Dept

UC Santa Barbara

Santa Barbara, CA 93106

recht@ece.ucsb.edu